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X-RAY TUBE CATHODE CUP STRUCTURE FOR FOCAL SPOT DEFLECTION

This application is a Continuation-in-Part of U.S. Application Serial No. 09/989,864, filed November 20, 2001.

Background of the Invention

The present invention pertains to the vacuum tube arts, and in particular to an x-ray tube cathode cup structure for deflecting a focal spot of a beam of electrons. It finds particular application in conjunction with rotating anode x-ray tubes for CT scanners and will be described with particular reference thereto. However, it is to be appreciated that the present invention will also find application in the generation of radiation and in vacuum tubes for other applications.

Conventional x-ray tubes include a vacuum enclosure and a source of a beam of electrons in the form of a cathode. The cathode includes a heated filament which emits electrons. The impact of the electron beam on the anode causes a beam of x-radiation to be emitted from the x-ray tube, typically through a beryllium window. A trend toward shorter x-ray exposure times in radiography has placed an emphasis on having a greater intensity of radiation and hence higher electron currents. Increasing the intensity can cause overheating of the x-ray tube anode. An electrical bias voltage is applied to the beam of electrons in order to control, to some extent, the size of the focal spot.

One way to control the size of the focal spot of the electrons on the anode more closely is to mount the

cathode filament within a cathode focusing or support cup member. Such a system is shown in U.S. Patent No. 4,689,809. A cathode cup is split into two portions, surrounding the filament. The portions are biased equal to or negative with respect to the filament. The biased cup reduces unwanted "wings," or diffused areas, appearing as part of the x-ray focal spot.

Other cathode cup and filament arrangements for controlling the size and shape of the electron focal spot on the tube anode are discussed in U.S. Patent Nos. 4,685,118, 5,224,143, and 5,065,420.

To minimize the power requirements of the focussing system and to maintain accurate positioning of the filament relative to the deflectors, it is desirable to mount both the deflectors and the filament to the same support. Cathode cups thus typically include a base or arm portion which supports the filament and a pair of deflectors. The deflectors are mechanically mounted to the base, but are electrically insulated from it. This is achieved through the use of ceramic insulators which are brazed to both the base and the deflectors in the form of a sandwich. The ceramic insulators include central bores through which a bolt is received for maintaining alignment of the components during brazing. To avoid shorting, the bolt is electrically isolated from the base. Such a cathode cup design is difficult to assemble, difficult to align, and is susceptible to shorting. This can occur if the material used to braze the ceramic insulator to the base or the deflector flows into the insulator bore that receives the bolt. Shorting can also occur due to natural plating of the ceramic insulator with metal vapor from the filament.

The present invention provides a new and improved x-ray tube and method which overcomes the above-referenced problems and others.

Summary of the Invention

In accordance with one aspect of the present invention, a cathode assembly is provided. The assembly includes a base. A filament is mounted to the base for delivering a stream of electrons. A deflector is carried by the base for deflecting the electrons and/or focusing the electrons into a beam. An insulator electrically insulates the deflector from the base. The insulator defines a bore. A rod is connected with the deflector adjacent a first end of the rod. The rod is received within the insulator bore.

In accordance with another aspect of the present invention, an x ray tube is provided. The x-ray tube includes an envelope which encloses an evacuated chamber. A cathode assembly is disposed within the chamber for providing a source of electrons. The cathode assembly includes a base supported in the envelope. A filament is mounted to the base for providing the electrons. A deflector is carried by the base for deflecting the electrons and/or focusing the electrons into a beam. An insulator electrically insulates the deflector from the base. The insulator defines a bore. A rod is connected with the deflector adjacent a first end of the rod, the rod being received within the insulator bore. An anode is disposed within the chamber and positioned to be struck by the electrons and generate x-rays.

In accordance with another aspect of the present invention, a method of assembling a cathode assembly is provided. The method includes attaching at least one rod to at least one deflector and attaching a metal tube in an insulator to define a bore for receiving the rod. The insulator is attached to a base. A filament assembly is attached to the base. The method further includes sliding the rod into the tube to mount the deflector to the base and attaching the rod to the tube.

One advantage of at least one embodiment of the present invention is that a cathode cup is electrically isolated from a filament.

Another advantage of at least one embodiment of

the present invention is that deflectors of a cathode cup are readily aligned with a filament.

Another advantage of at least one embodiment of the present invention is that components of a cathode cup are accurately aligned.

Another advantage of at least one embodiment of the present invention is that deposition of vaporized filament material on to insulators which space the deflectors from a base assembly is minimized by reducing the line of sight between the filament and the insulators.

Still further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

Brief Description of the Drawings

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating a preferred embodiment and are not to be construed as limiting the invention.

FIGURE 1 is a schematic sectional view of a rotating anode x-ray tube according to the present invention;

FIGURE 2 is a side view of a cathode assembly of the x-ray tube of FIGURE 1;

FIGURE 3 is a front perspective view of the cathode assembly of FIGURE 2;

FIGURE 4 is a top view of the cathode assembly of FIGURE 2;

FIGURE 5 is a sectional view of the cathode assembly through line B-B of FIGURE 4;

FIGURE 6 is an exploded perspective view of the cathode assembly of FIGURE 2;

FIGURE 7 is an enlarged perspective view of a cathode assembly according to an alternative embodiment of the invention; and

FIGURE 8 is a sectional view of the cathode assembly of FIGURE 7.

Detailed Description of the Preferred Embodiments

With reference to **FIGURE 1**, a rotating anode x-ray tube **1** of the type used in medical diagnostic systems for providing a beam of x-ray radiation is shown. The tube includes an anode **10** which is rotatably mounted in an evacuated chamber **12**, defined by an envelope or frame **14**. A heated element cathode assembly **18** supplies and focuses an electron beam **A**. The cathode is biased, relative to the anode **10** such that the electron beam flows to the anode and strikes a target area **20** of the anode. A portion of the beam striking the target area is converted to x-rays **B**, which are emitted from the x-ray tube through a window **22** in the envelope. The cathode assembly includes a cathode cup or head **24**, which is supported in the envelope by an arm **26** of the cathode assembly **18**, which is connected at its other end to a central support structure **28**.

The target **20** of the anode is connected to a shaft **40**, which is supported by bearings **42** in a neck portion **46** of the evacuated envelope **14** and driven by an induction motor **48**. The induction motor includes a stator **50**, outside the envelope, which rotates a rotor **52** connected to the shaft relative to a stationary bearing housing **54**. The anode is rotated at high speed during operation of the tube. It is to be appreciated that the invention is also applicable to stationary anode x-ray tubes, rotating cathode tubes, and other electrode vacuum tubes.

With reference now to **FIGURES 2-6**, the cathode head **24** includes a base **60**, which may be integrally formed with the arm **26** or mounted thereto, for example, by brazing or welding, or by affixing the arm to the base with bolts **62** or other suitable attachment members threaded through holes **64** in the base (**FIGURE 4**). A filament assembly **66** is supported by the base. As shown in **FIGURE 2**, two insulative filament supports or posts **67, 67′** are provided for

supporting respective ends of the filament. Alteratively, as shown in **FIGURE 3**, one of the insulative filament supports is omitted, and the filament is grounded through the base **60**. The support or supports **67, 67'** are received through corresponding bores **68, 68'**, which extend axially through the base such that an electron-emitting portion or tip **70** of the filament assembly is spaced from the base. The filament supports may be fixed in this position by brazing the filament supports **67, 67'** to the respective bore or by other means, such as threading a threaded portion of the filament supports **67, 67'** to corresponding threads in the respective bore. It will be appreciated that two or more filament assemblies may be used in place of the single filament assembly shown, if desired. The filament supports **67, 67'** may be formed from ceramic, or other suitable insulative material. Preferably, each support has a tube **71, 71'** of nickel and/or Kovar™ brazed into an interior bore thereof (not shown). In the case of the embodiment of FIGURE 3, the tube **71** is received through corresponding bore **68**, and is preferably brazed directly thereto. Niobium shanks **73, 73'** at ends of the tungsten filament are received through respective bores in the tubes **71** after the tubes have been mounted in the respective filament support or supports **67, 67'** (**FIGURE 5**). When it is time to position the filament **66**, the two niobium shanks at the ends of the filament are inserted into the respective tubes **71**. A microscope is used to adjust the height of the filament tip **70**. When the filament tip is correctly positioned relative to the base **60**, the tubes **71, 71'** are crimped around the respective shanks **73, 73'** to maintain the position of the filament until welding takes place, for example, by laser welding the shanks to the tubes **71, 71'**. Prior to welding, the tungsten filament is preferably annealed to grow the filament into a single crystal tungsten structure, for example, by flashing a high current through the filament in a hydrogen atmosphere.

The filament assembly **66** is connected by conductors **74**

to a suitable power source **76** outside the envelope (**FIGURE 3**). Although a wire filament is illustrated, it is to be understood that other electron sources are also contemplated, including thin film filaments, and the like.

Deflectors **80, 82** are carried by the base **60** in a manner which electrically insulates the deflectors from the base. Two deflectors are shown in **FIGURE 3**, although a single deflector, or more than two deflectors, could alternatively be used. The deflectors are positioned in close proximity to the filament tip **70** for deflecting and/or focussing the beam of electrons emitted by the filament. This allows the size and location of a focal spot **86** on the target (**FIGURE 1**) to be controlled and adjusted.

As shown in **FIGURE 3**, the deflectors **80, 82** are generally mirror images of each other and are positioned on opposite sides of the filament tip **70**. Each deflector has an upper surface **90** and lower surface **92** (the terms "upper" and "lower" being used with reference to the orientation shown in **FIGURE 3**, the upper surface being closer to the base **60**). A side wall **94** of the deflector projects inwardly, towards the filament, in the region of the filament tip **70**, thus providing a relatively narrow gap **96** between respective projecting portions **97, 97'** of the two deflectors in the region of the filament tip.

The deflectors **80, 82** may be formed from molybdenum, or other suitable temperature resistant, electrically conductive material. The base **60** may also be formed from molybdenum, or may be formed from less expensive, easier to machine materials, such as nickel, since it does not need to withstand as high temperatures as the deflector.

With particular reference to **FIGURES 4** and **6**, the deflectors **80, 82** are spaced and insulated from the base by insulators **98, 100, 98', 100'**. As shown in **FIGURE 4**, four insulators are employed, two for each deflector. For stability, it is preferable to use two (or more) insulators for each deflector, spaced longitudinally from each other,

although it will be appreciated that a single insulator may be used. For ease of reference, the cathode will be described with reference to two deflectors, each having two insulators. As shown in phantom in **FIGURE 4**, the filament tip **70** extends between the forward and rear shanks **73, 73'** along a line which is generally coincident with the longitudinal axis of the base **60** and perpendicular to a line B-B between the forward pair of insulators **98, 100** and is equally spaced from each insulator **98, 100, 98', 100'** at its closest point thereto.

As best shown in **FIGURES 5** and **6**, each insulator **98, 100, 98', 100'** comprises a cylindrical block **104, 105,** each with a central axial bore **106**. A first, lower portion **110** of each block **104, 105** is received within a correspondingly shaped cylindrical socket **112** in the deflector **80, 82**. It will be understood that different shaped insulator blocks may be used, such as rectangular blocks and a corresponding shaped socket in the defector provided. As will be appreciated, two sockets are formed in each deflector to receive corresponding insulator blocks, a total of four sockets in all. Each socket extends partway into the deflector, preferably, about half way.

The socket **112** has a slightly larger diameter than the corresponding block **104, 105,** such that a gap **116** spaces the insulator from the deflector adjacent a cylindrical side **118** and preferably also a base **119** of the insulator block **104, 105.** The gap **116** is preferably about 70-100 microns in width, such that a space is maintained between the insulator **104, 105,** and the deflector **80, 82**. This reduces the risk of shorting out. In service, insulators sometimes become coated with a plating layer formed by evaporation of filament material. Leaving a gap between the insulator and the deflector allows for a fairly thick layer of plating material to accumulate without resulting in shorting out.

A second upper (in **FIGURE 6**) portion **120** of each insulator block **104, 105** is received within a cylindrical passageway **122** in the base (four passageways are shown in

FIGURE 4). The passageway **122** is chamfered to create a smaller diameter portion **124** at the upper end thereof with a shoulder **126** for providing an upper stop for the insulator block **104, 105**.

The insulator blocks **104, 105** are formed from an electrically insulating material, such as alumina. For example, 94% purity or 99% purity alumina may be used, such as AD 94, AL 500, or equivalent purity. Al_2O_3 meeting ASTM Standard D2442 Type 4 is an exemplary insulating material. For effective electrical insulation of the deflector from the base (and the filament), the insulators preferably provide a resistance of at least 720 giga-ohm.

A pair of deflector rods **130, 130', 132, 132'**, formed from an electrically conductive material, such as niobium, are mounted to each deflector **80, 82** (i.e., four rods in total) and are received through the corresponding bore **106** of the insulator blocks **104, 105**. The deflector rods **130, 130', 132, 132'** are electrically connected to a respective bias supply **134, 135** by suitable wiring **136** (**FIGURE 3**). One bias supply is preferably provided for each deflector. The rod is electrically insulated from the base **60** by the corresponding insulator block **104, 105** and by a gap **138** at the upper end portion **124** of the insulator passage **122**.

The deflector rods **130, 130', 132, 132'** provide an electrically conductive path to the respective deflector **80, 82** for biasing the deflector to an appropriate voltage for deflecting or focusing the electron beam. For example, as the two deflectors **80, 82** both become more negative, relative to the filament, the size of the focal spot is reduced. When they become sufficiently negative, the electron beam is turned off. If one deflector is more negative than the other, the focal spot moves away from the more negative part. This latter result can be achieved by biasing only one of the deflectors and having the other deflector at the same potential as the filament. Because of the close proximity of the deflectors to the filament, a

small bias is able to deflect or focus the beam. The two bias supplies **134, 135** may be computer controlled to permit automatic control of the width and positioning of the focal spot to a multiplicity of locations.

Each rod **130, 130', 132, 132** is preferably brazed to the deflector prior to insertion of the rod in the corresponding insulator block bore **106**. As shown in **FIGURE 6**, each deflector has a depression **140**, such as central hole machined in the base of each socket **112**, and shaped to receive one end **142** of the respective rod **130, 130', 132, 132**. To attach the rod to the deflector, the rod is positioned in the hole **140**, together with a small piece of a suitable braze material, and the assembly heated to an appropriate temperature to braze the two components **130, 80** together.

In an alternative embodiment, pairs of deflector rods **130, 130'** and **132, 132'**, respectively, are connected at their ends **142** by a connecting portion (not shown) to form a generally U-shaped member. In this embodiment, the depression **140** takes the form of a slot, shaped to receive the connecting member therein. The connecting portion is positioned in the slot **140**, together with a small piece of a suitable braze material, and the assembly heated to an appropriate temperature to braze the two components together. Other methods of attaching the rod **130, 132** to the deflector **80, 82** are also contemplated.

Each of the insulator blocks **104, 105** preferably has a cylindrical tube **146, 147, 146', 147'** mounted axially in the central bore **106** for receiving the corresponding rod. Although only two tubes **146, 147** and two blocks are shown in the view of **FIGURE 6**, it will be appreciated that a tube is provided for each insulator block. Thus, for this embodiment, four tubes **146, 147, 146', 147'** are employed, as shown in **FIGURE 4**. Each passageway, insulator block bore, and corresponding tube and rod are preferably concentrically arranged, as shown in **FIGURE 4**. As shown in **FIGURE 5**, the tube **146, 147** has an upper end which extends beyond the

upper end of the insulator block, when installed, and is preferably of sufficient length to extend above the base **60** when the insulator block **104, 105** is located in the base. At a lower end, the tube **146, 147**, when installed, is preferably flush with the base **119** of the insulator block, or may be slightly set back within the block.

The tube **146, 147** has an axially extending bore **148** therethrough with an internal diameter which is only slightly larger than the diameter of the corresponding rod **130, 132** so that the rod fits snugly in the tube bore. For example, the rod **130, 132** may have an OD of 0.100 cm + 0.000/-0.018 and the corresponding tube **146, 147** an ID of 0.104 cm + 0.025/-0.000. The tube is preferably formed from a material which is readily welded to the rod, for example, by laser welding. Exemplary materials for forming the tube include nickel and Kovar™. The tube **146, 147** is attached to the insulator block **104, 105** by brazing the two parts together, for example, by heating the tube and block with a suitable braze material between them. The quantity of braze material used should be sufficient to attach the parts firmly, without overflowing significantly at ends of the insulator block. This step is preferably carried out prior to inserting the insulator block into the base passageway **122**.

The insulator blocks **104, 105** for the deflectors and the insulative support(s) **67, 67′** for the filament assembly **66** (or tube **71**, in the case of the embodiment of **FIGURES 3** and **4**) are brazed to the cup base **60** by heating the base and insulator, together with a suitable brazing material. The deflector insulator blocks **104, 105** and the insulative supports **67, 67′** may be brazed into the base at the same time. However, in this embodiment, because the insulator blocks **104, 105** are inserted from the bottom of the base and the insulative support(s) **67, 67′** for the filament are inserted from the top of the base, it may be preferable to braze first one set of insulators (either the filament or the deflector insulators) and then flip the base

over and braze the other set of insulators.

The brazing material for the insulator blocks **104, 105** is preferably positioned in the shelf region. The brazing material can be the same type as is used to attach the tube to the insulator block and the rod to the deflector. However, since the brazing is preferably carried out in three separate steps (rod to deflector, tube to block, and block to base), the brazing material for each of the three joints can be a different material which is compatible with the parts to be joined and heated to an appropriate temperature for the respective braze material to melt.

To provide a suitable surface for brazing, the insulator block preferably has a very thin surface coating **150** of a metallizing material, such as a molybdenum-manganese or tungsten-manganese composite material (shown exaggerated in the thickness in **FIGURE** 6). The coating may be deposited on the block by suitable deposition techniques to a thickness of about 5-20 microns. Preferably, the metallizing layer extends over only a portion of the outer surface of the blocks, such as at the upper end of the block in the region where the braze material will be applied, to minimize risk of shorting between the base and the deflector.

The insulator tubes **146, 147** are welded or otherwise attached to the rods **130, 132**, for example, by laser welding. This step is preferably carried out after the insulators **104, 105** have been brazed into the base. This allows the deflectors to be properly aligned with the filament. The length of the deflector rods **130, 132** is preferably selected such that, when the deflectors are correctly positioned, the rods are level with or protrude by a small amount from the upper ends of their respective tubes **146, 147**.

To ensure alignment of the filament tip **70** with the deflectors, the insulative filament posts **67, 67'** are preferably seated in the base **60** and the ends of the

filament **66** positioned (crimped, or crimped and welded) before inserting the deflector rods **130, 132** into the insulator tubes **146, 147**. The rods are then inserted into their respective tubes. A gauge (not shown) of the appropriate thickness is then inserted between the deflector and the base to determine an appropriate gap **152** between the deflector and the base. The base and deflector are pushed towards each other (the rods sliding in their respective tubes) until the base and deflector contact the gauge.

Prior to laser or otherwise welding the insulator tubes **146, 147** to the deflector rods **130, 132**, the respective insulator tubes and rods are optionally crimped together to hold the desired set position. The two deflectors **80, 82** are preferably positioned so that the filament tip **70** is approximately halfway between top and bottom surfaces of the deflector. This minimizes the risk of metallization of the insulator by material evaporating from the filament and avoids a "line of sight" being created in which material from the filament can travel in a straight line to the insulator. As can be seen from **FIGURE 5**, the deflectors are positioned such that material evaporating from the filament tip **70** will be inhibited by the projections **97, 97'** from traveling directly towards the insulator blocks, the closest direct paths **x** and **y** to the insulators **98, 100** taking the material to the base **60**, rather than to the insulator.

In an alternate embodiment, illustrated in **FIGURES 7** and **8**, a cathode assembly **216** is shown. The cathode assembly is similar to assembly **18** and includes a base **220**, similar to base **60**, with four bores **222, 222', 224, 224'** for receiving deflector insulator blocks **226, 226', 228, 228'**. The bores and insulator blocks are similar to those shown in **FIGURES 2-6**. However, in this embodiment, the bores are constructed for the insulator blocks to be mounted from an upper surface **230** of the base, rather than from the lower surface **232**, as is the case in the embodiment of **FIGURES 2-6**. This allows the cathode filament support(s) **67, 67'** (not

shown) and the insulator blocks **226, 226′, 228, 228′** to be mounted from the same side **230** of the base and facilitates brazing by allowing the cathode filament supports **67,67′** and insulator blocks **226, 226′, 228, 228′** to be readily brazed in the same operation.

As shown in **FIGURE 8**, the bores each have an tapered shoulder portion **240** between a widened upper portion **242** and a narrower lower portion **244** of the bore. The insulator blocks **226, 226′, 228, 228′** are shaped with a shoulder portion **246** between a widened upper portion **248** and a narrower lower portion **250** of the block. The lower portion of the block is received at its lower end by the corresponding deflector **80, 82**. The shoulder portion **246** of the block sits on the bore shoulder portion **240**. Prior to brazing, a small amount of brazing material is placed in the generally triangular space between the two shoulders **246, 240** for sealing the two components together when brazed. The shoulder portion **246** of the insulating block may be metallized prior to inserting the block into the bore to provide a good weld joint. An insulation gap **252** may be provided between the narrow portion **250** of the insulating block and the lower portion **244** of the bore. The gap ensures that even if a small portion of material evaporated from the filament tip enters the lower portion of the bore, it is deposited adjacent the surface **232**, and the insulative barrier between the deflector and the base is not impaired. A similar arrangement (not shown) is used for brazing the filament support(s) **67, 67** into the respective bores **68, 68′** to that described previously. Assembly of the cathode assembly **216** is otherwise the same as for the embodiment of **FIGURES 2-6**.

Other components of the cathode assembly are analogous to those described for the embodiment of **FIGURES 2-6** and are given the same numerals. As for the earlier embodiment, deflector rods **130, 132** are brazed to the deflectors **80,82** with brazing material **260** (**FIGURE 8**). The rods are then positioned in the respective tube bores **148** and, after

adjusting the height of the deflector, the tubes are crimped and welded or otherwise attached to the rods.

While in this embodiment, both the deflector insulator blocks and the filament supports are inserted from the top of the block, it is also contemplated that the base may be configured for inserting both the insulator blocks and filament supports from the bottom of the base.

A preferred method of assembling the cathode is thus as follows:

a) braze the rods **130, 132** to the deflectors **80, 82,**

b) braze the tubes **146, 147** to the insulator blocks **104, 105,**

c) braze the insulator blocks **104, 105** (or **226, 228**) and filament supports **67,67'** (or tube **71**) to the base **60,**

d) set the filament tip **70** height by positioning and fixing filament shanks **73, 73'** into tubes **71, 71'** in the insulative supports **67,67',**

e) set the deflector height with a gauge and crimp the tubes **146, 147** to the rods **130, 132,**

f) weld the tubes **146, 147** to the rods **130, 132.**

As will be appreciated, step b) may alternatively be carried out before or concurrently with step a) and steps a), b), and/or c) may be carried out after step d).

Assembling the components stepwise, with three separate brazing steps a), b), c), and a welding step f), rather than brazing the insulator to the base and to the deflector in a single brazing operation, minimizes tolerance stackups due to improper alignment of the three components. The deflectors **80, 82** are easily aligned with respect to the filament tip **70**, simply by sliding the rods **130, 132** up and down in their respective tubes **146, 147**. Having two (or more) tubes which fit snugly to the corresponding rods and thus guide their movement ensures that the deflector remains parallel with the base as it is being positioned.

The invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.